SYSTEMATIC DESIGN OF BIOLOGICALLY INSPIRED ENGINEERING SOLUTIONS

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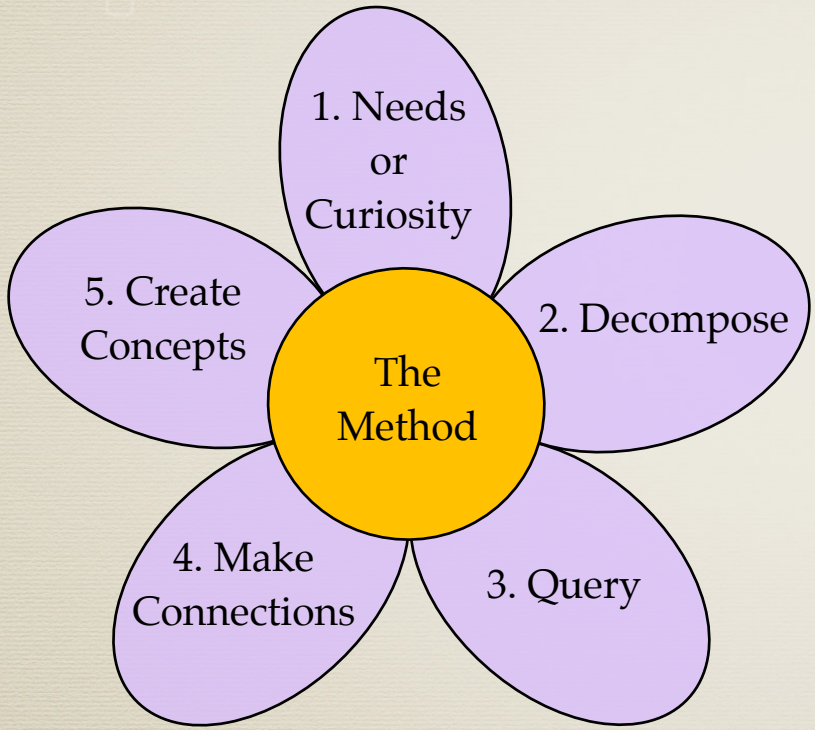
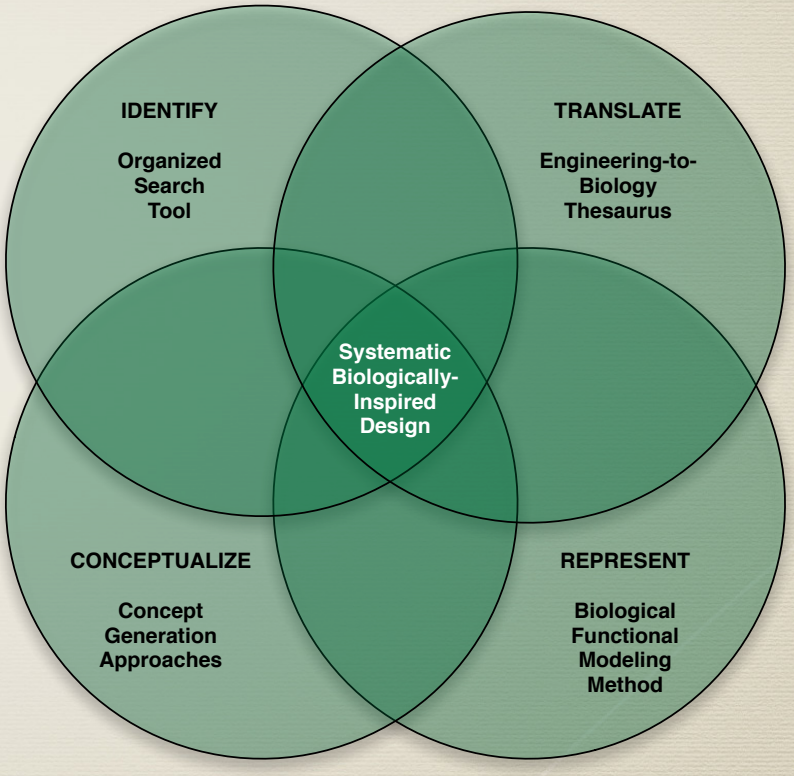
October 4, 2017

NIEA SUMMIT 2017
Nature-Inspired Exploration for Aerospace

The combination of a methodology and supporting design tool framework facilitate systematic design.



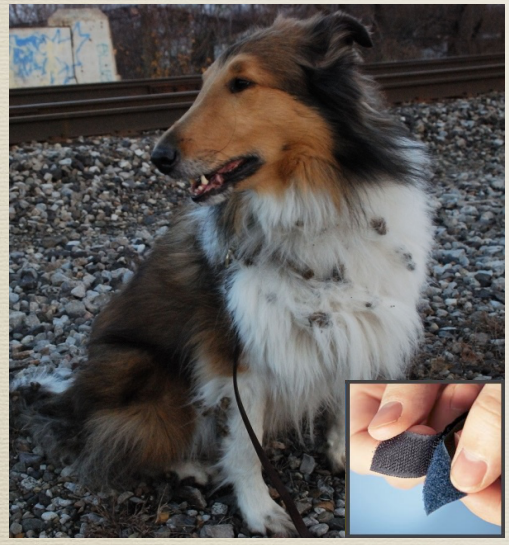
Methodology



Design Tool Framework

The spectrum of inspiration approaches eludes to the struggle of how to navigate the vast amount of biological information.

Chance
Observation



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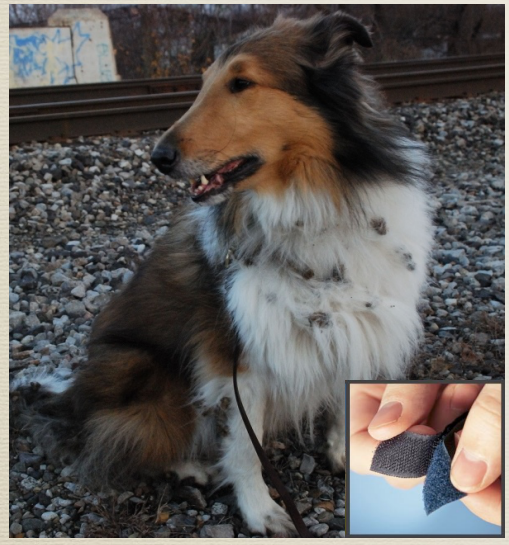
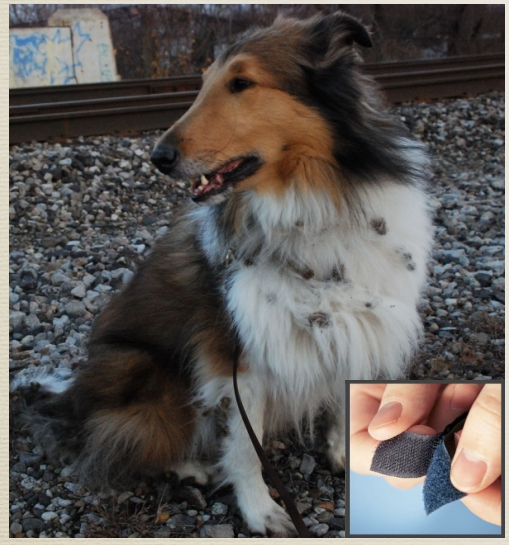


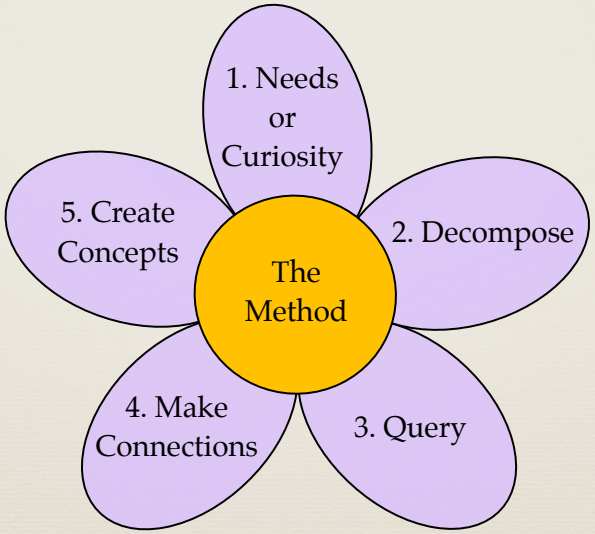
Dedicated Research

This work aims to remove the element of chance and reduce the amount of time and effort required to developing solutions.

Chance Observation

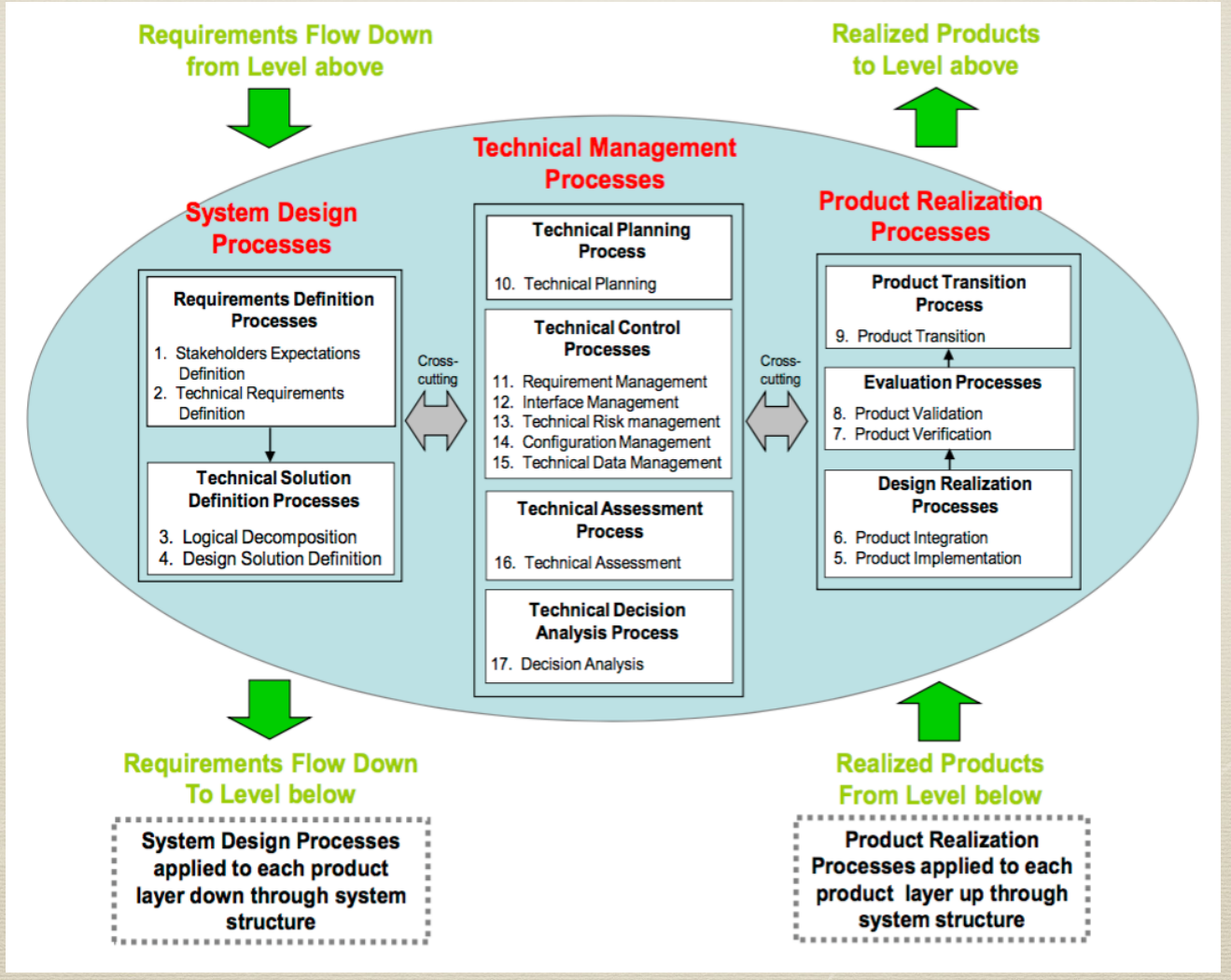


Systematic Exploration



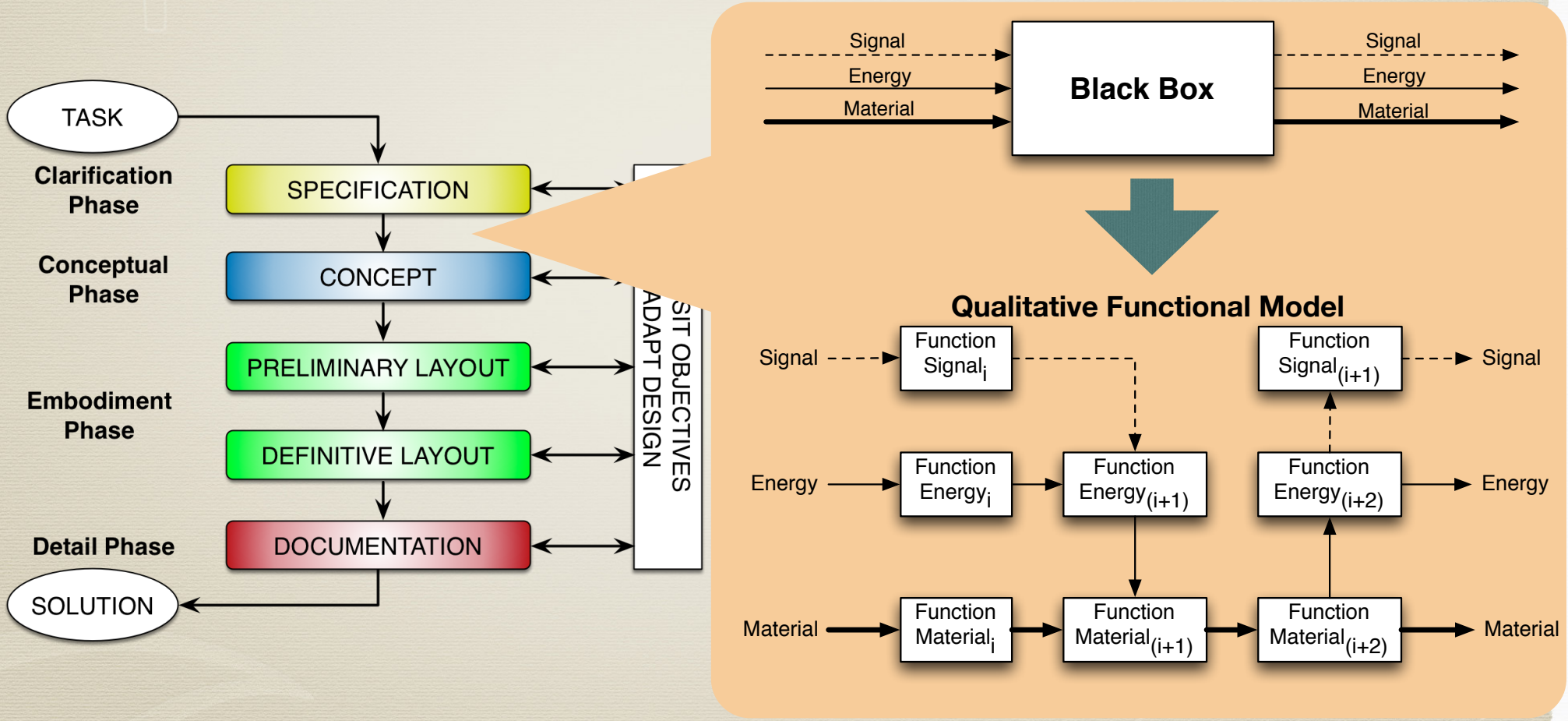
Dedicated Research

Systematic procedures help to render designing comprehensible by providing a prescriptive process.



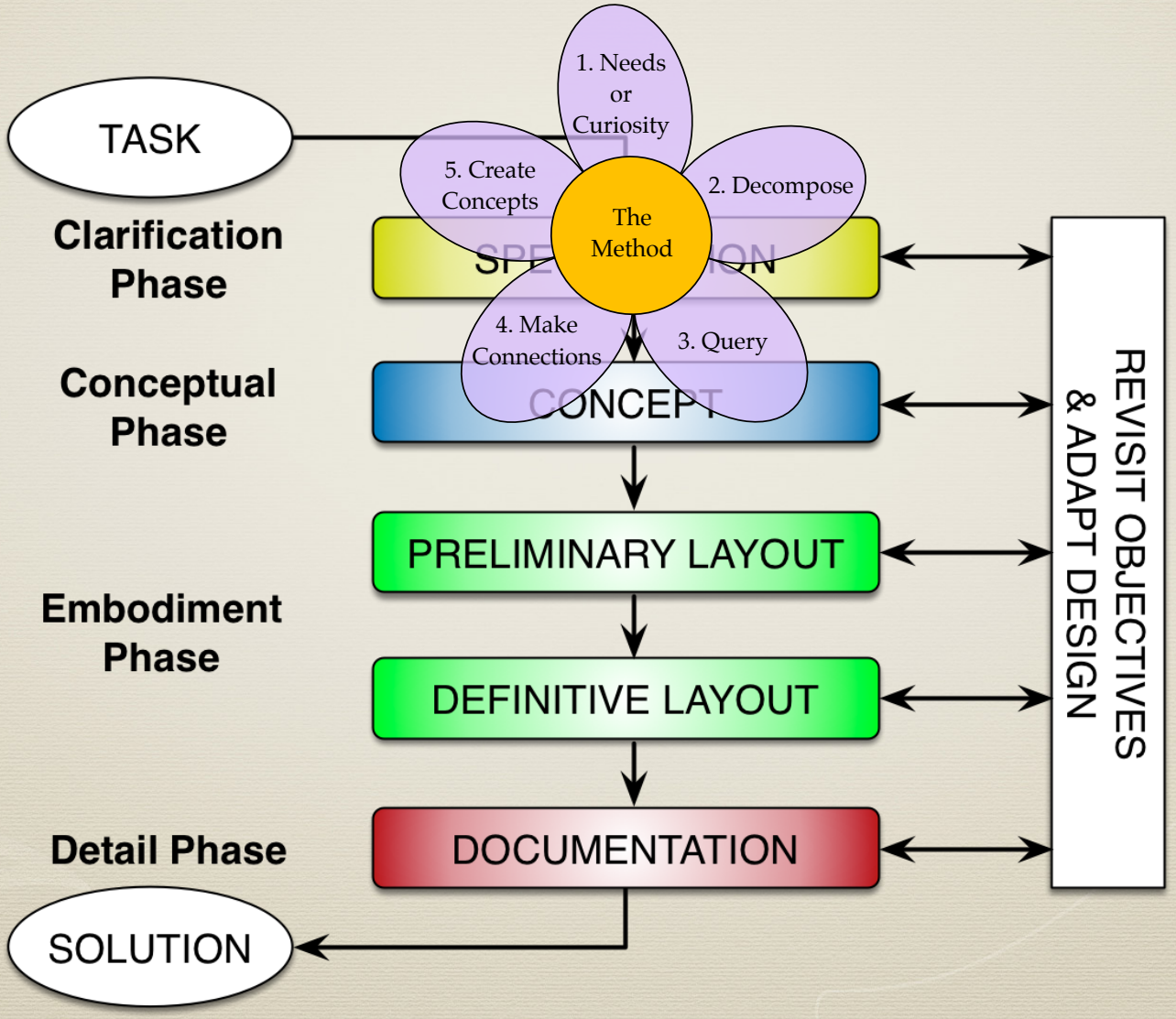
NASA Systems Engineering Handbook (2016) NASA/SP-2016-6105 Rev2. https://nodis3.gsfc.nasa.gov

Function-based design requires defining or conceptualizing an artifact, product, or system in terms of function.

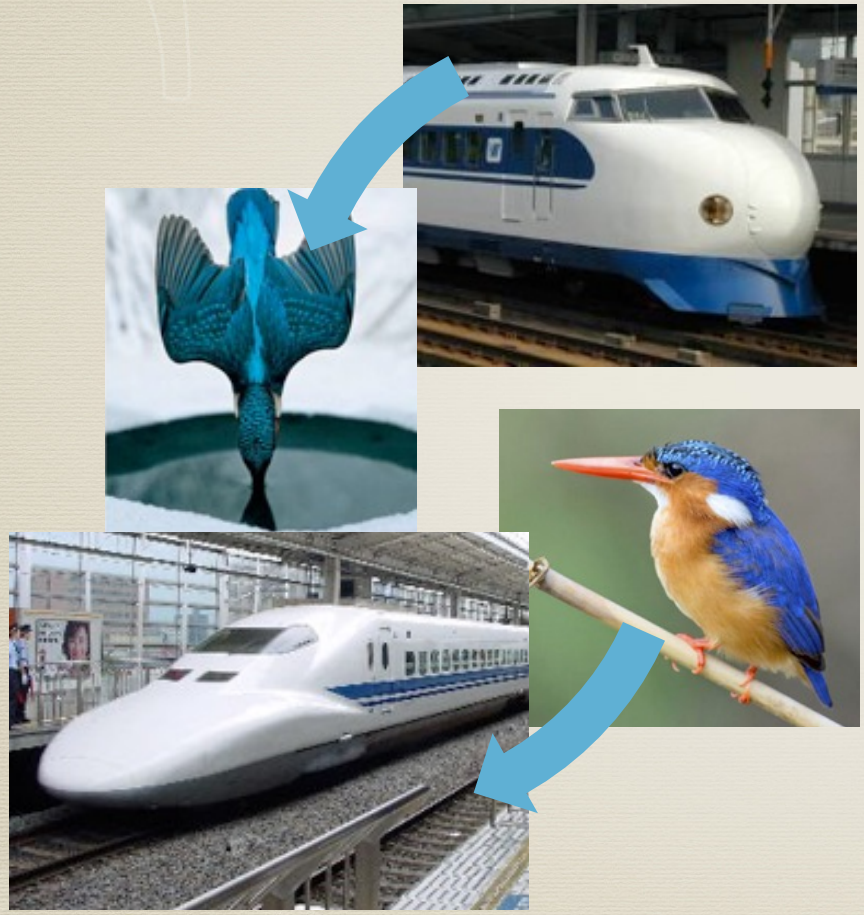


Pahl, G. and W. Beitz (1984), Engineering Design: A Systematic Approach, Design Council, London.

The methodology and framework assist with early design phases with the expectation that traditional design tasks will follow.



The methodology and framework support two major paths to biologically inspired solutions.

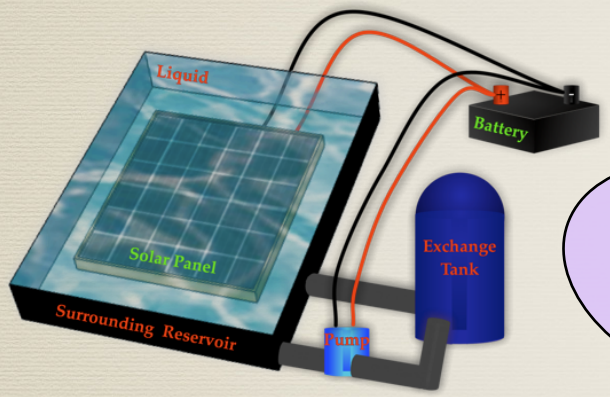


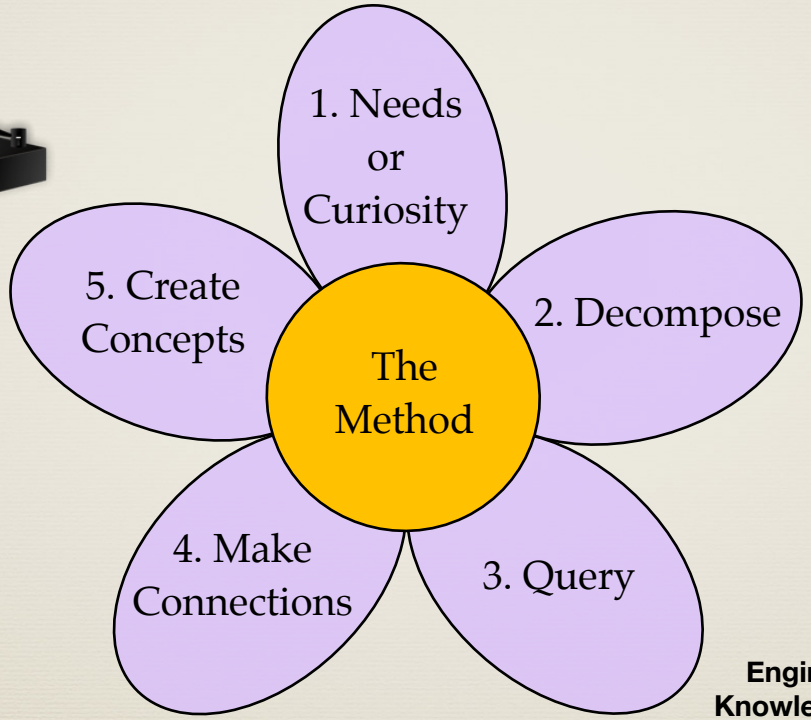
Problem-Driven
(needs)

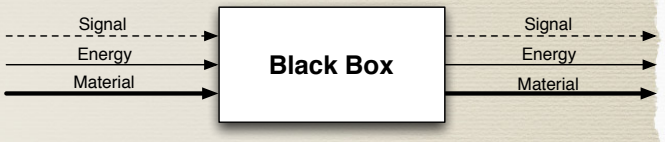
Biology-Driven
(curiosity)

www.asknature.org; whalepowercorp.wordpress.com

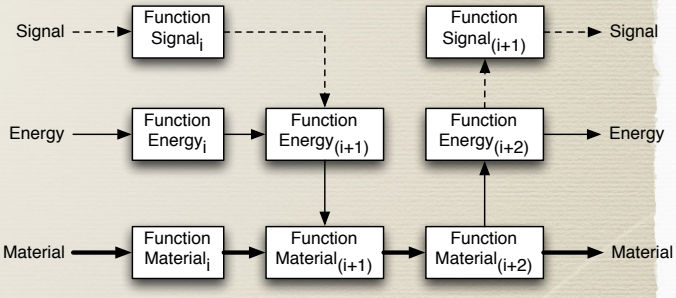
As a function-based design methodology, functional abstractions are recognized as a way to connect biology and engineering.

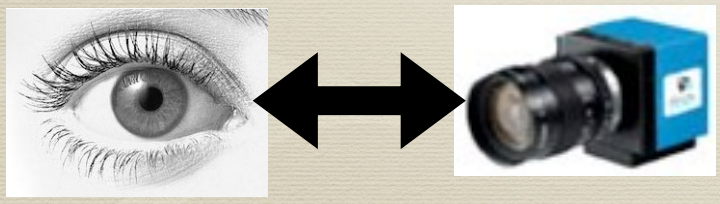




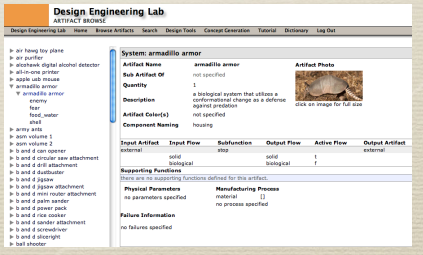


Qualitative Functional Models

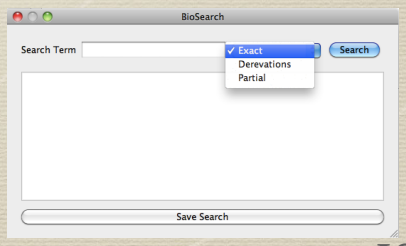




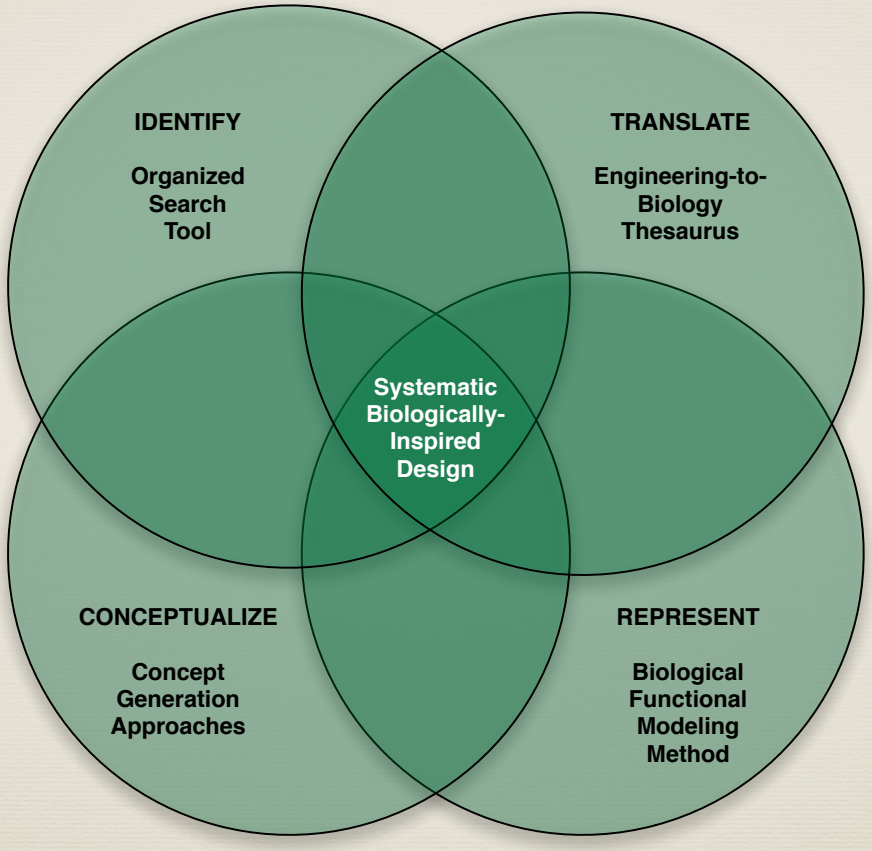
Engineering Knowledge Base



Biological Knowledge Base

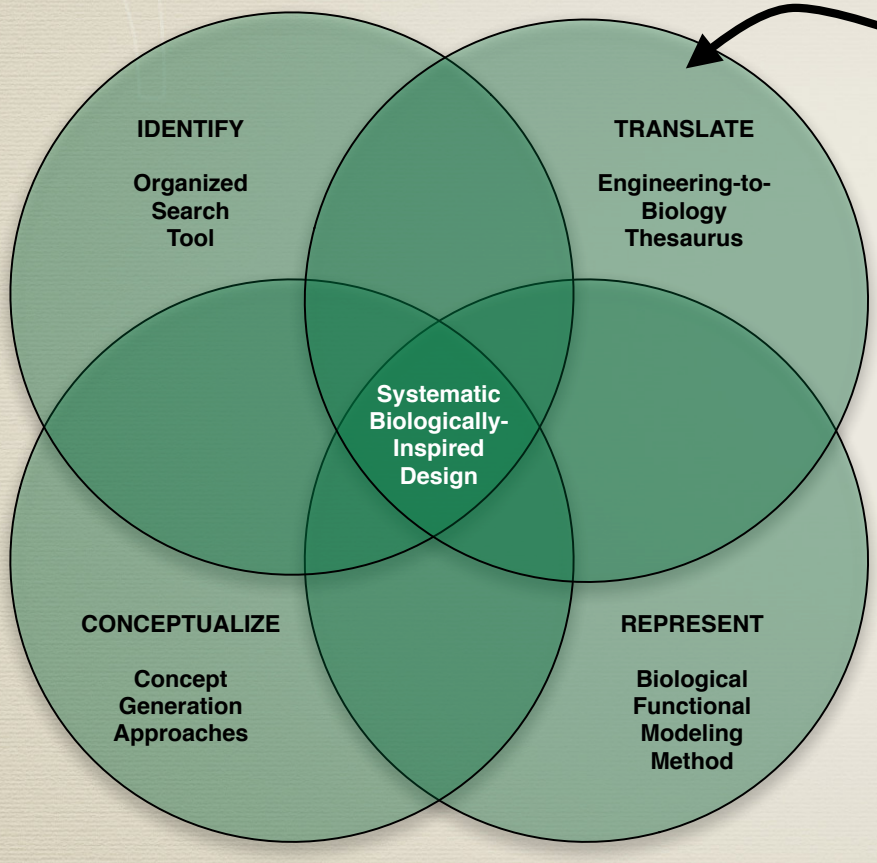


This framework allows a designer to *identify*, *translate* and *represent* biological information in an engineering context.

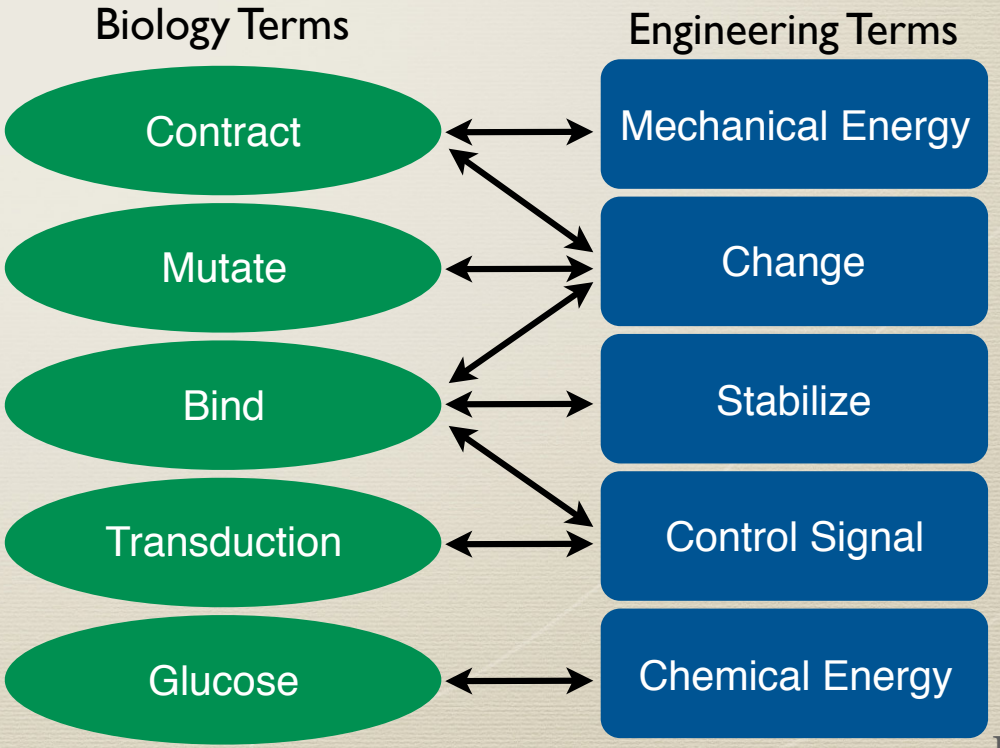


So that it can be used for inspiration and *conceptualization* of engineering solutions.

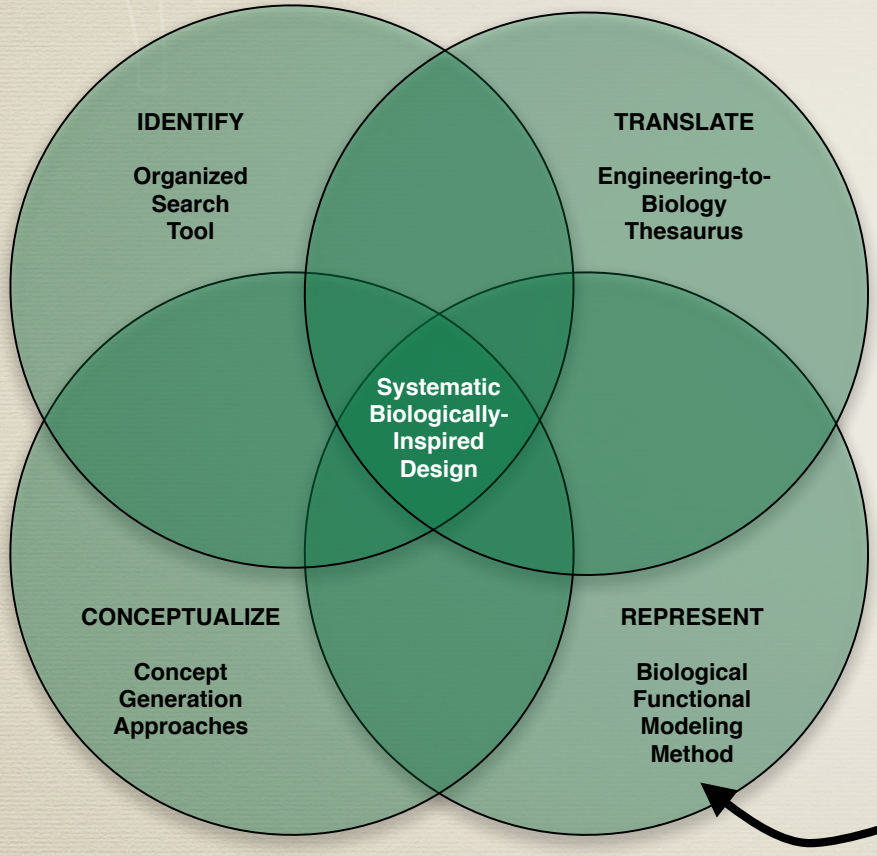
Translation using an *Engineering-to-Biology Thesaurus* addresses terminology and communication issues.

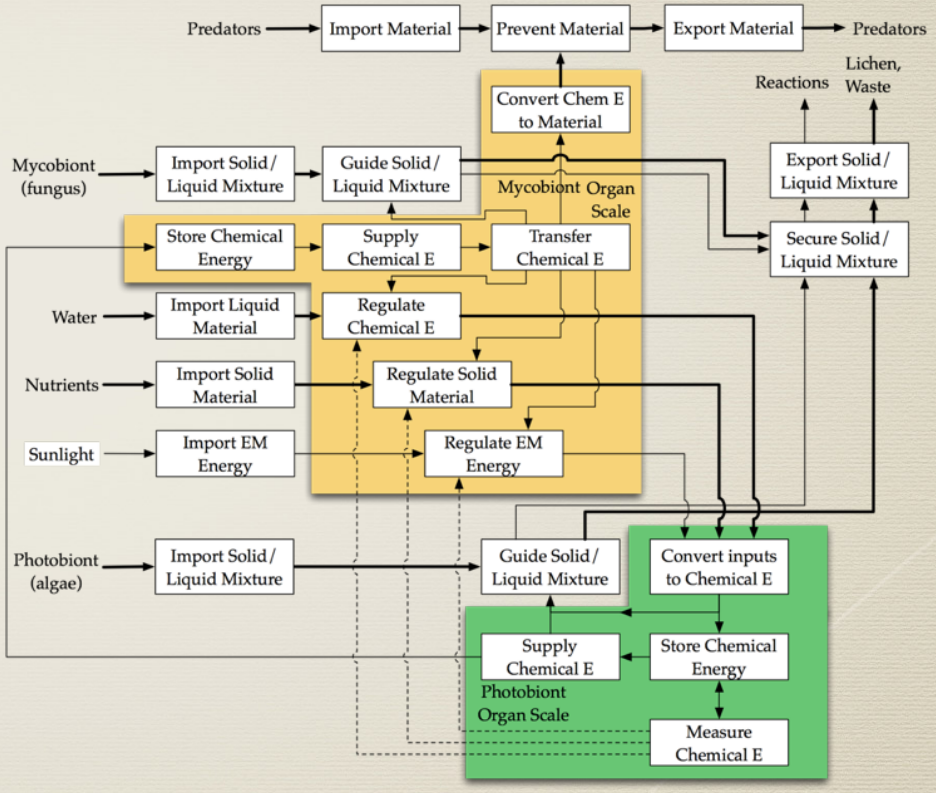


- Maps synonymous biology and engineering terms
- Assists with translating biological information into an engineering context



Biological functional modeling supports biology-driven design and assists with understanding biology from a engineering context.

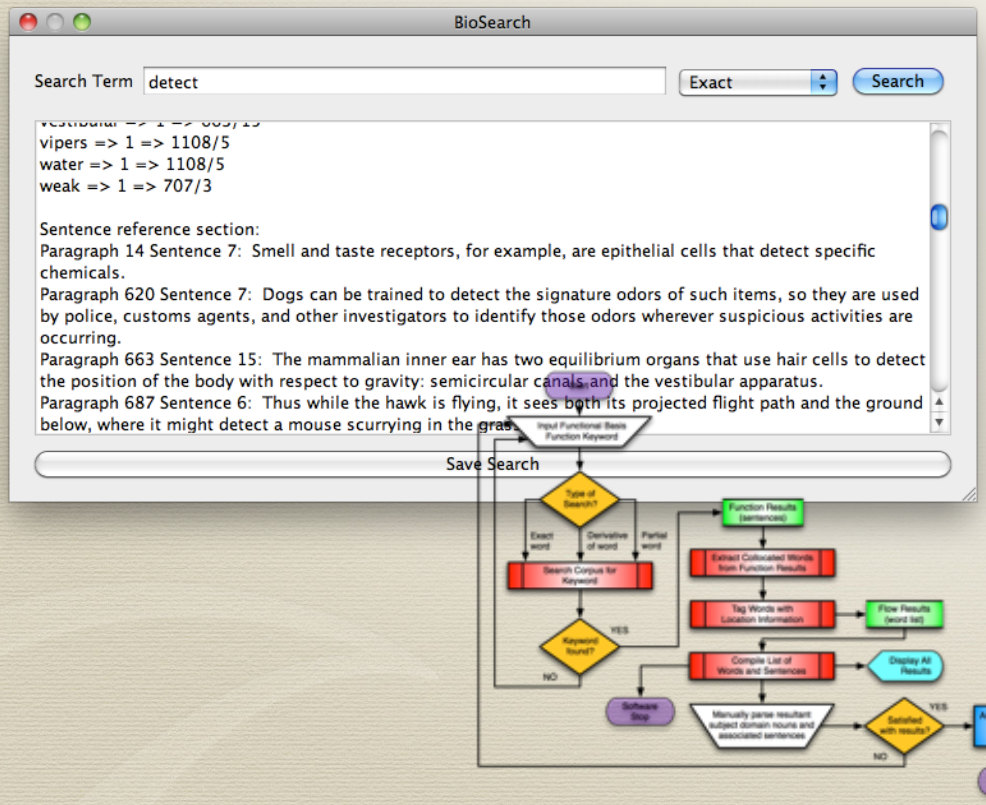


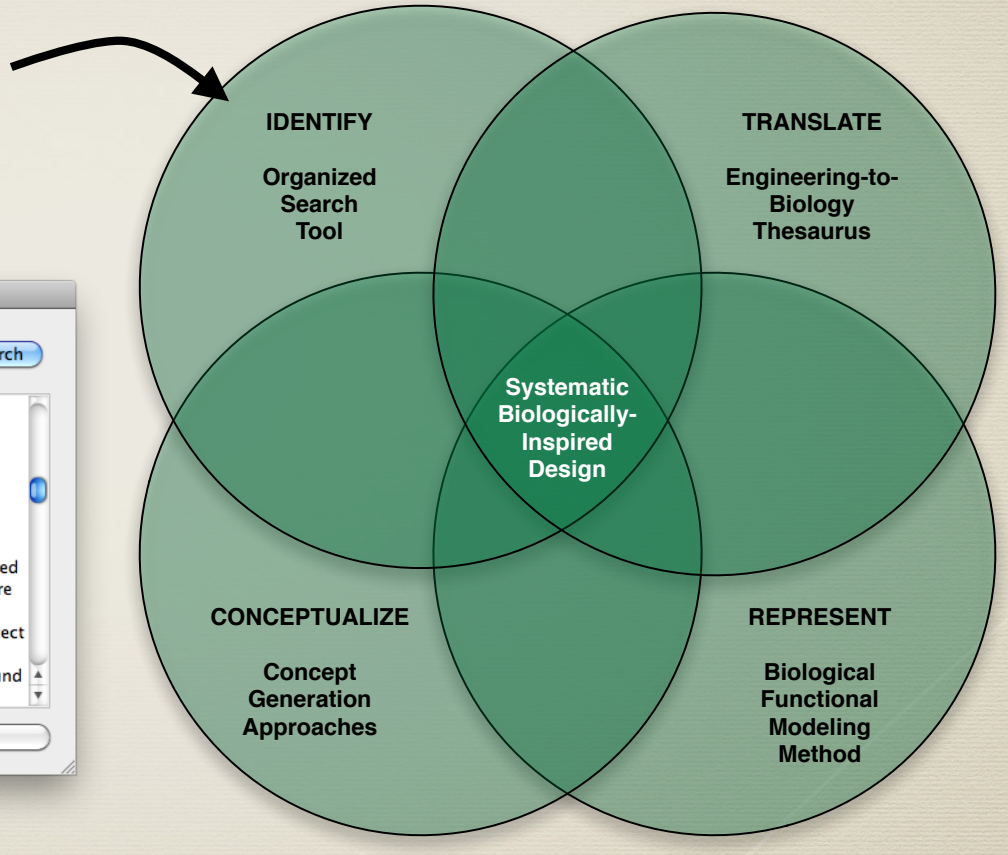


- Assists designers with capturing biological physiology, strategy, morphology, behavior

An *Organized Search tool* addresses difficulties in identifying relevant biological systems for inspiration for problem-driven design.

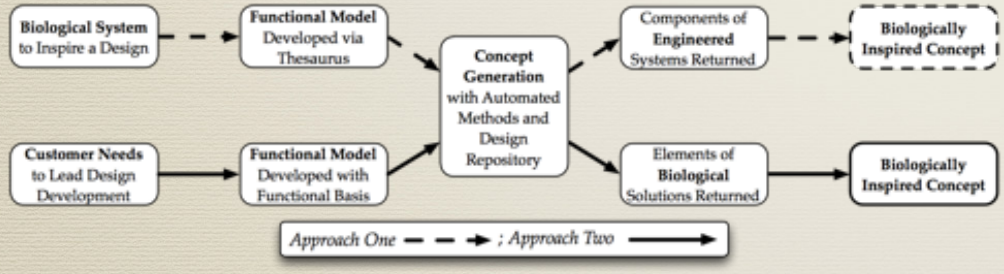
- Algorithm for finding solutions in non-engineering texts based on engineering function

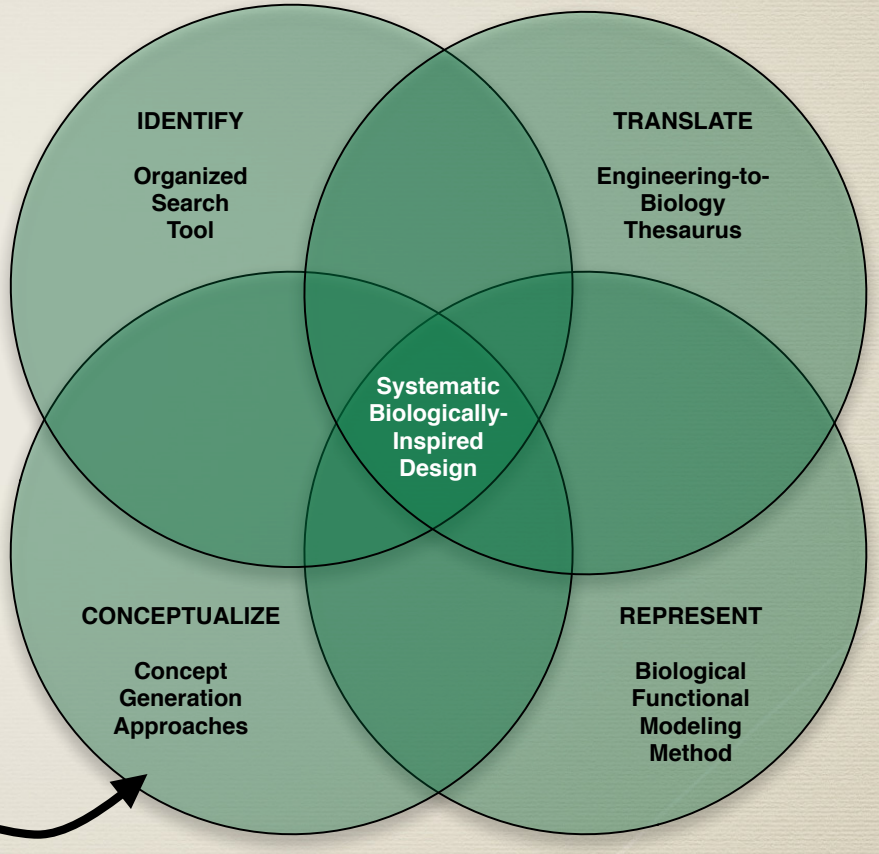




Concept generation approaches support both problem- and biology-driven design.

- Assists with connection building by leveraging existing automated design tools
- Promotes creativity





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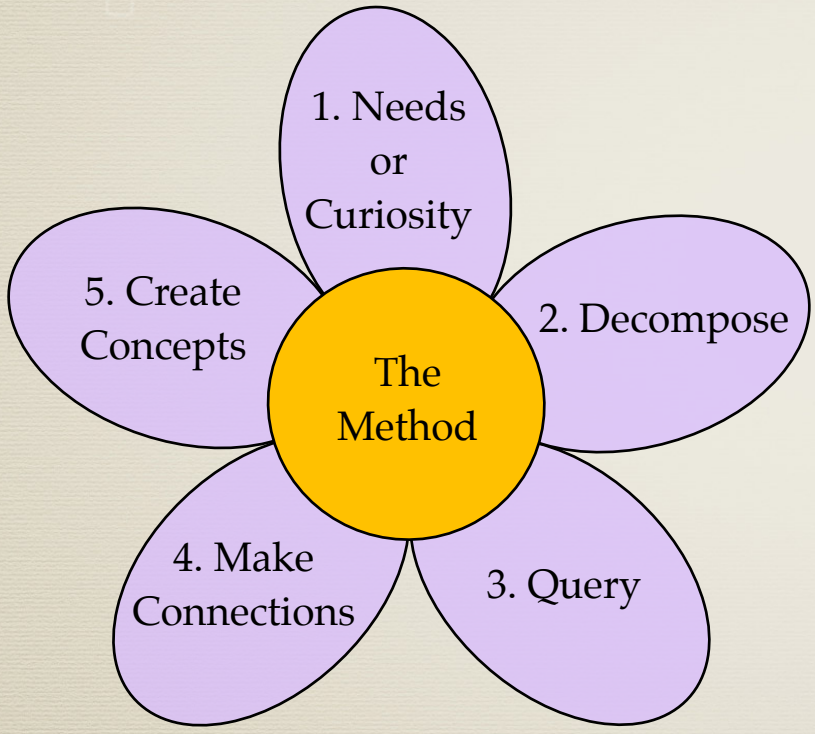
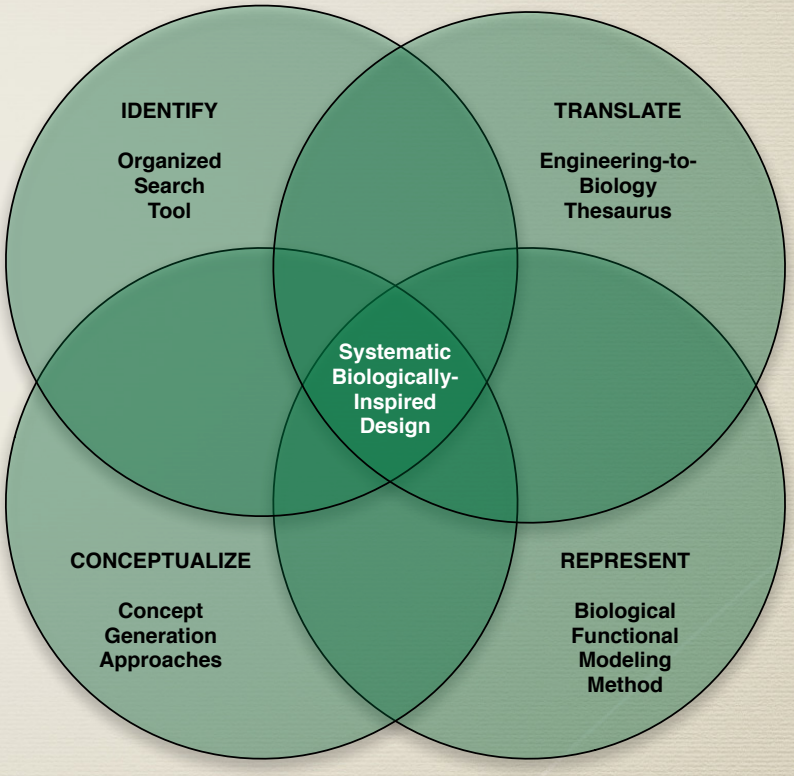
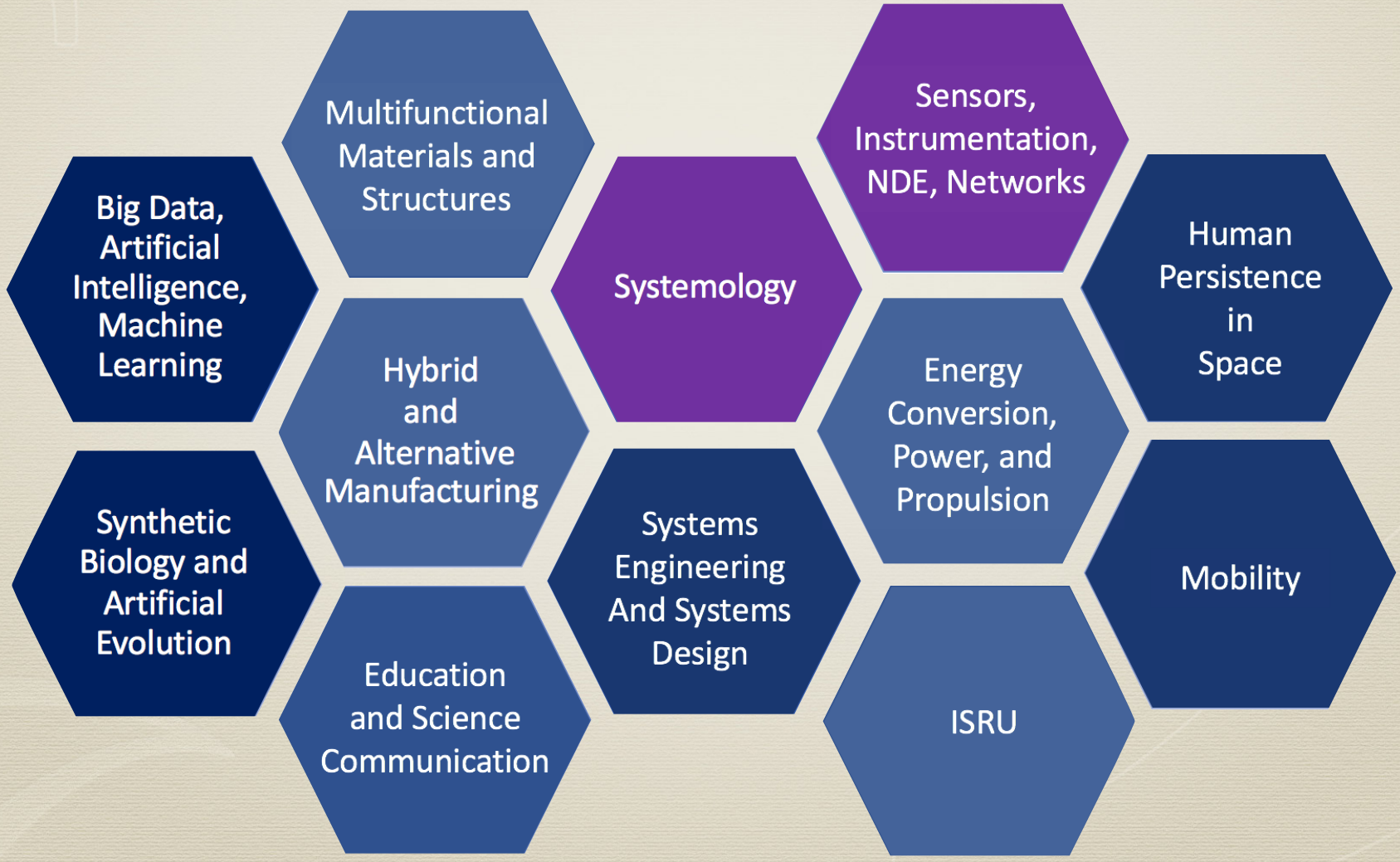


Methodology



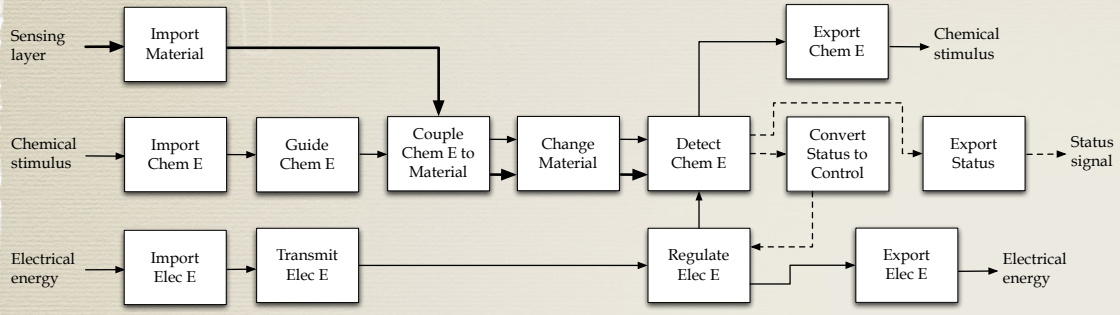
Design Tool Framework

This work supports nature-inspired exploration for aerospace by meeting the objective of the V.I.N.E. Systemology cluster.



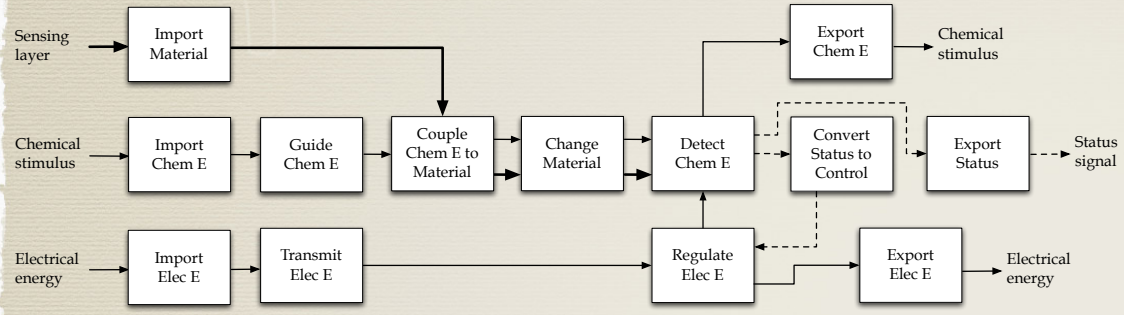
https://www.grc.nasa.gov/vine/ecosystem/find-a-cluster/

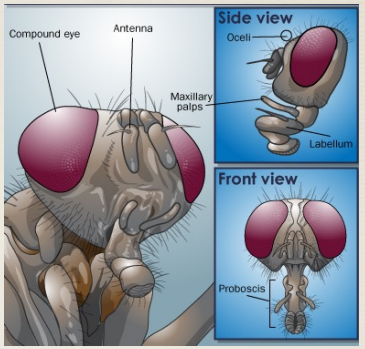
A guard cell and tropomyosin inspired chemical sensor was created following the problem-driven path.



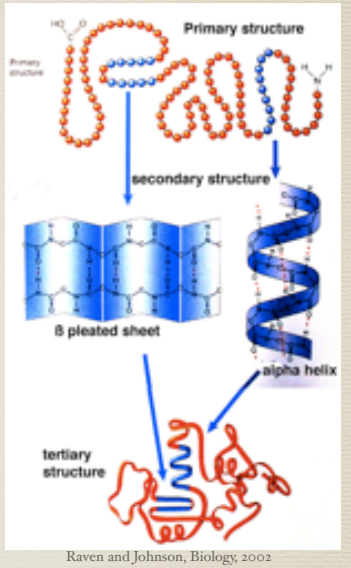
The chemical sensor functional model captures the needs and is used to **identify** biological systems that *change material* in the presence of a chemical and that *detect chemicals*. Over 20 biological systems were identified.

A guard cell and tropomyosin inspired chemical sensor was created following the problem-driven path.





http://animals.howstuffworks.com/insects/housefly1.htm



Raven and Johnson, Biology, 2002

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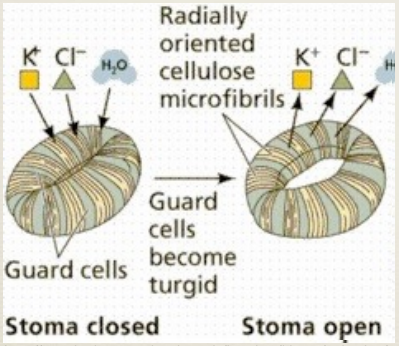

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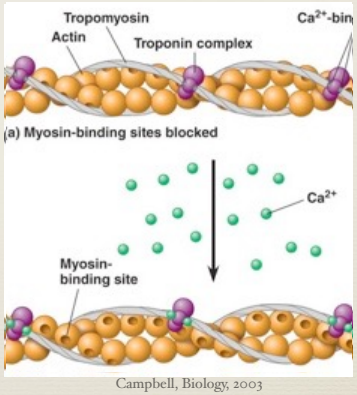
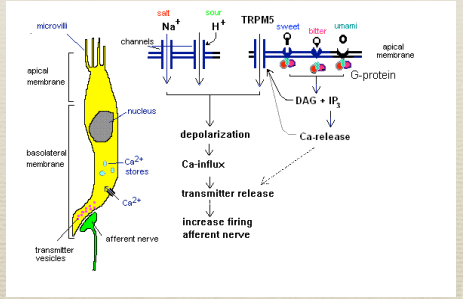


Campbell, Biology, 2003



http://www.cf.ac.uk/biosi/staffinfo/jacob/teaching sensory/taste.html

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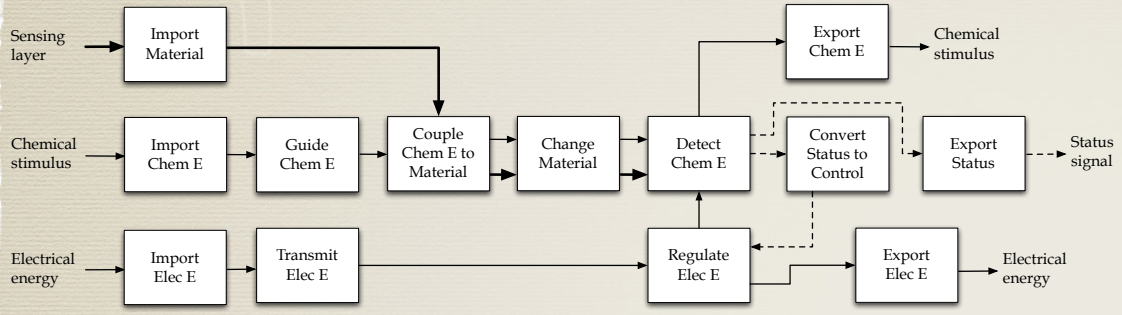

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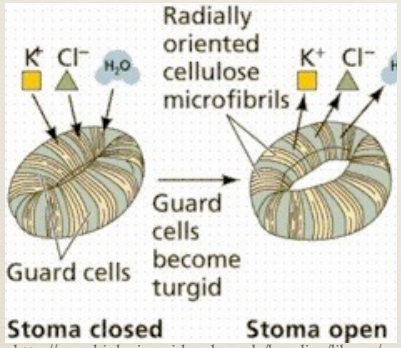

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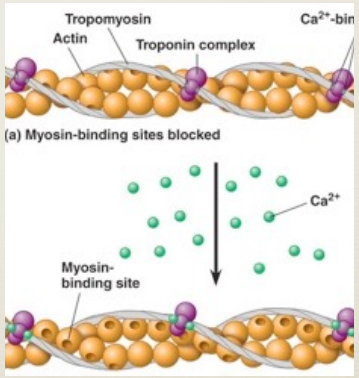
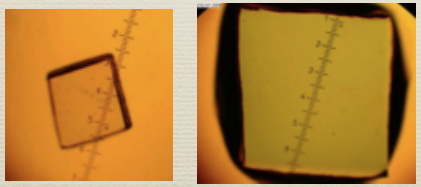
Guard Cell Physiology



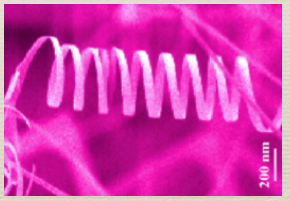
Campbell, Biology, 2003

Troponin and Tropomyosin Morphology



Chemomechanical Polymer

Schneider, Kato, Strongin; Sensors 2007



Nanospring

Wang 2009

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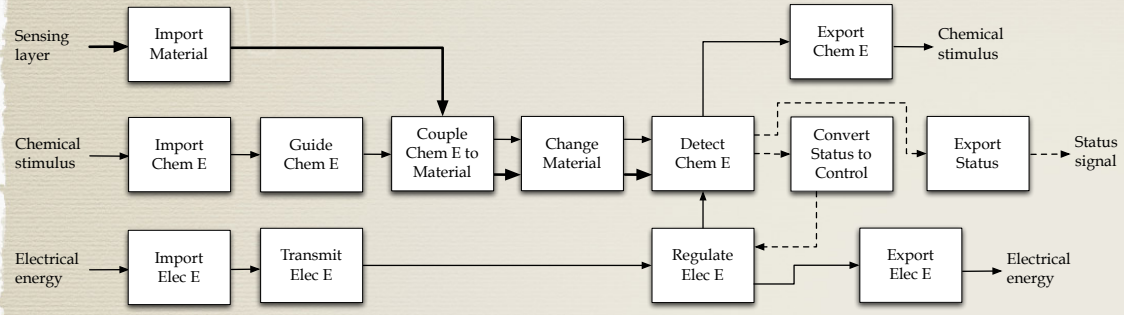

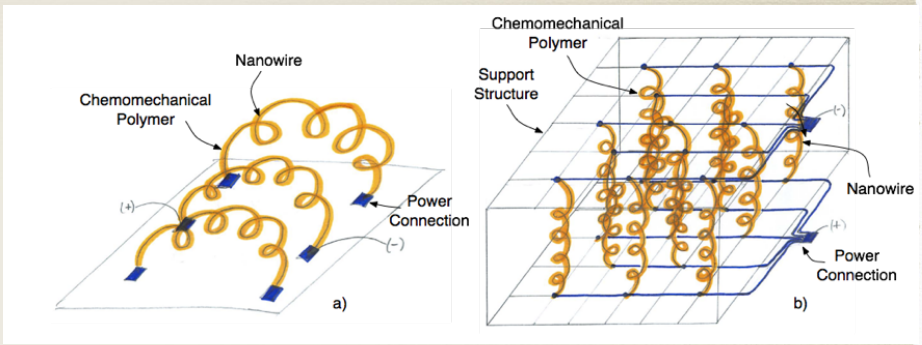

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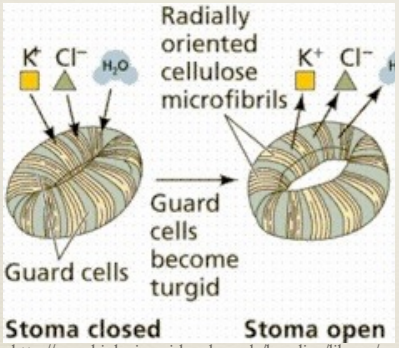

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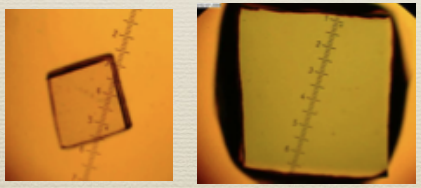

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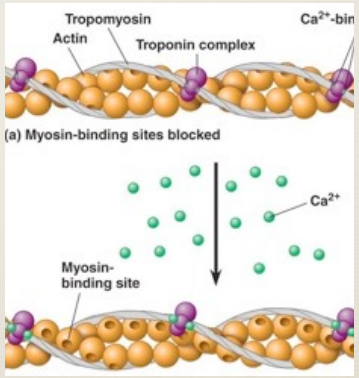


Campbell, Biology, 2003

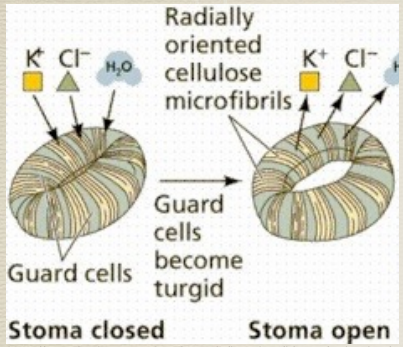
Troponin and Tropomyosin Morphology

Nanospring

Wang 2009

Through **translation,** inspiration from the physiology (function) of the guard cell coupled with the morphology (form) and physiology of tropomyosin resulted in two innovative **concept variants** for the chemical sensor.

A guard cell and tropomyosin inspired chemical sensor was created following the problem-driven path.



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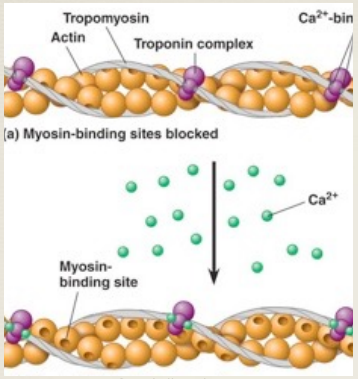
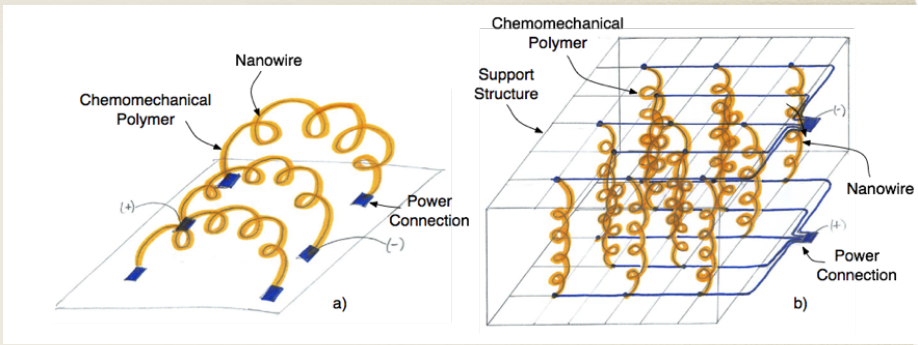


Campbell, Biology, 2003



What was Learned

- A change in physical shape allowed detection to occur
- Pre-processing or local processing happens at the stimuli site. Rather than actively process all stimuli, the stimulus intensity must meet a critical threshold or critical magnitude in order to trigger a sensory signal that elicits a response

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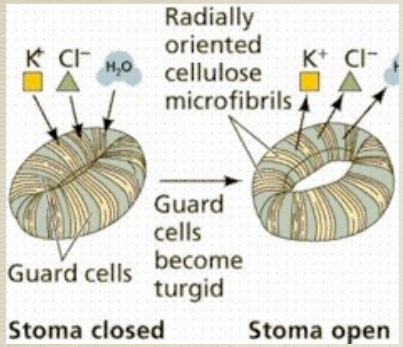

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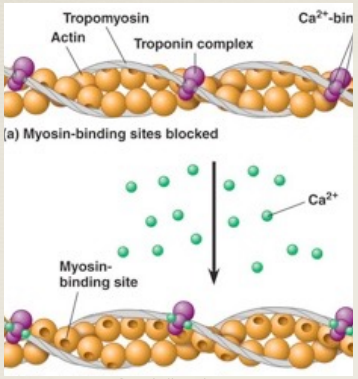

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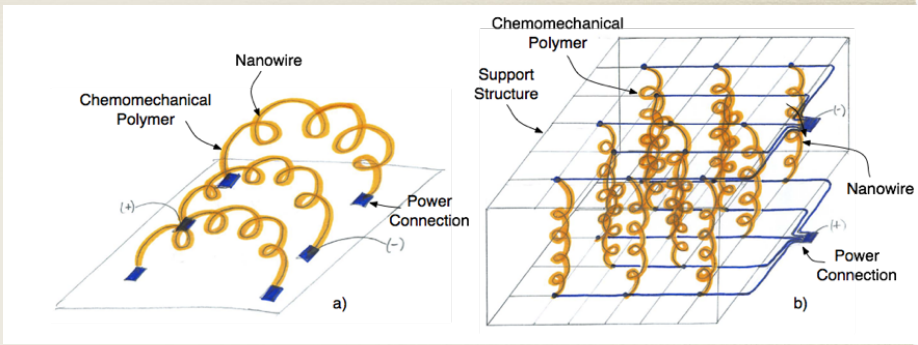

What was Learned

- A change in physical shape allowed detection to occur
- Pre-processing or local processing happens at the stimuli site. Rather than actively process all stimuli, the stimulus intensity must meet a critical threshold or critical magnitude in order to trigger a sensory signal that elicits a response

How to reduce data processing streams

Closing Remarks

- This work contributes a design methodology and supporting framework of tools that enables designers to ***intentionally create*** biologically inspired solutions from a problem- or biology-driven approach.
- ***Systematically exploring*** the biological space enables one to discover innovative solutions without requiring expert-level knowledge, but rather a broad knowledge of many fields.
- ***Supports*** nature-inspired exploration for aerospace through integration with the V.I.N.E. research clusters.

THANK YOU FOR YOUR TIME AND ATTENTION!

Please contact me if you would like to try out the method or tools, or collaborate.

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To Learn More

- Nagel, J.K.S. (2016) "Systematic Bio-inspired Design: How Far Along Are We?" International Council of Systems Engineering (INCOSE) INSIGHT, vol. 19(1), pp. 32-35. doi: 10.1002/inst.12070.
- Nagel, J.K.S., Stone, R.B., McAdams, D.A. (2014) "Function-based Biologically-Inspired Design." Chapter 5 in Biologically Inspired Design: Computational Methods and Tools, A. Goel, D.A. McAdams, R.B. Stone (eds.), Springer, ISBN: 1447152476.
- Nagel, J.K.S. (2014) "A Thesaurus for Bioinspired Engineering Design." Chapter 4 in Biologically Inspired Design: Computational Methods and Tools, A. Goel, D.A. McAdams, R.B. Stone (eds.), Springer, ISBN: 1447152476.
- Nagel, J.K.S. (2013) "Guard Cell & Tropomyosin Inspired Chemical Sensor." Micromachines, Special issue: Bioinspired Microsensors and Micromachines, vol. 4, pp. 378-401. doi:10.3390/mi4040378
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- Nagel, J.K.S., Nagel, R.L., Stone, R.B. (2011) "Abstracting Biology in Engineering Design." International Journal of Design Engineering, special issue Nature in Design, vol. 4(1) pp. 23-40.
- Nagel, J.K.S., Nagel, R.L., Stone, R.B., McAdams, D.A. (2010) "Function-Based, Biologically-Inspired Concept Generation." Artificial Intelligence for Engineering Design, Analysis and Manufacturing, special issue Biologically Inspired Design, vol. 24(4), pp. 521-535.
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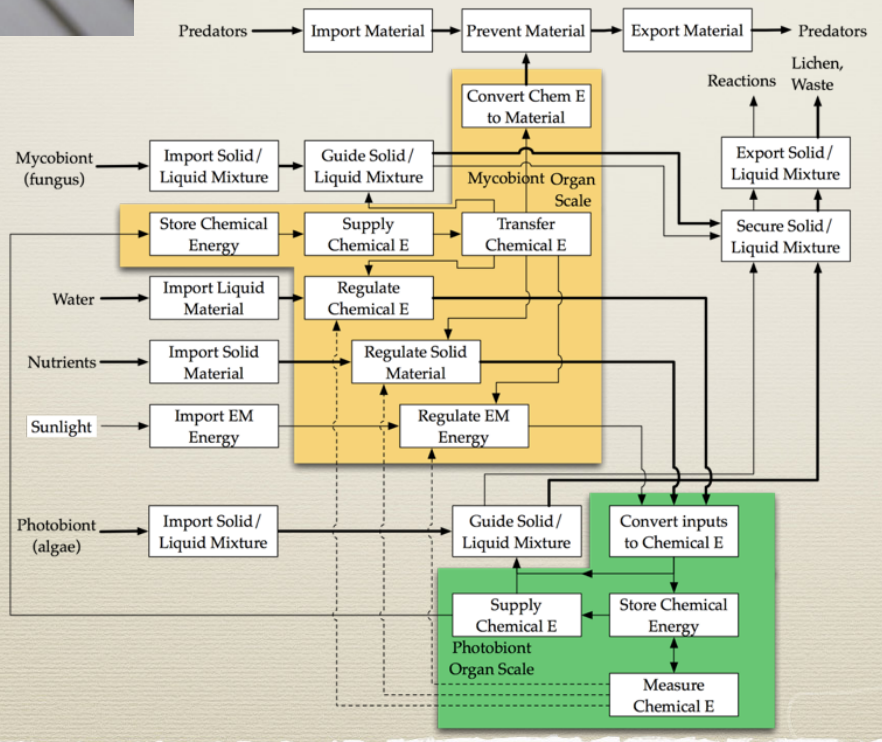
EXTRA EXAMPLE

A lichen inspired adaptable solar energy system was created following the biology-driven path.

A lichen inspired adaptable solar energy system was created following the biology-driven path.

The symbiotic organism lichen, comprised of an algae and fungus, was **translated** and **represented** as a biological functional model.



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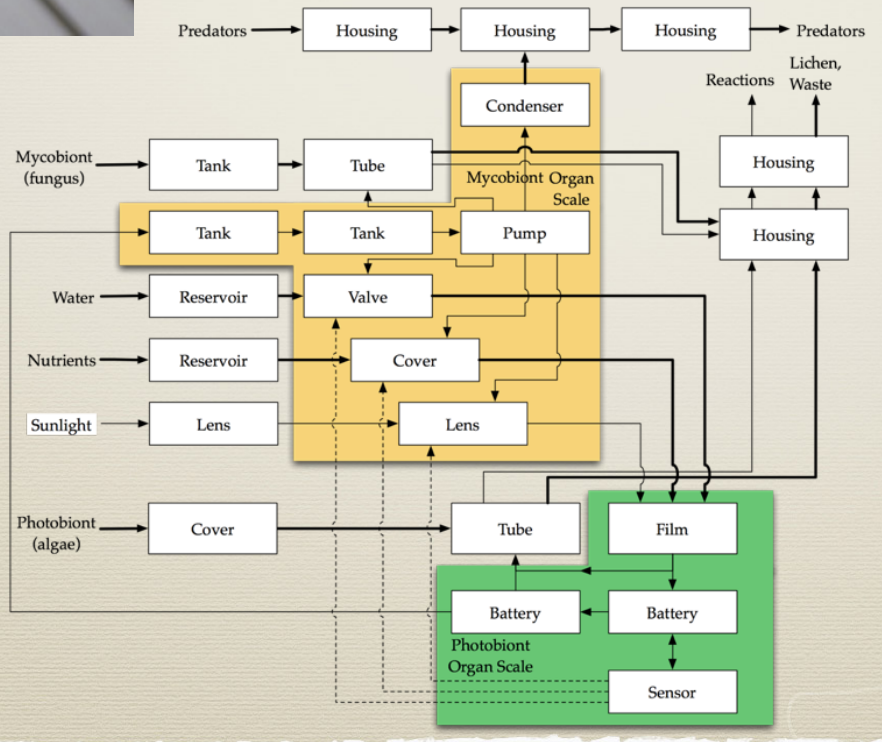

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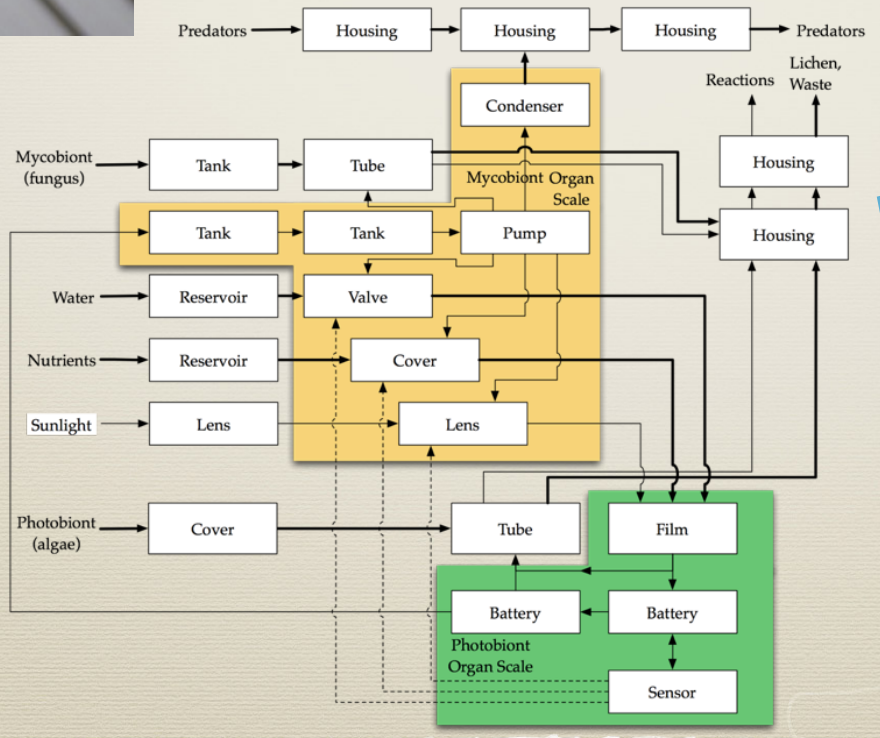

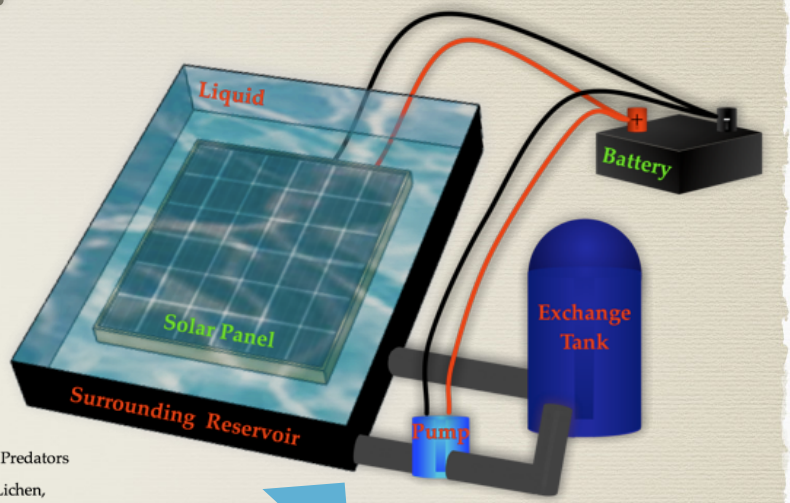

The functional model was used to identify analogous engineered components, which were used to **conceptualize** the innovative solar energy system.

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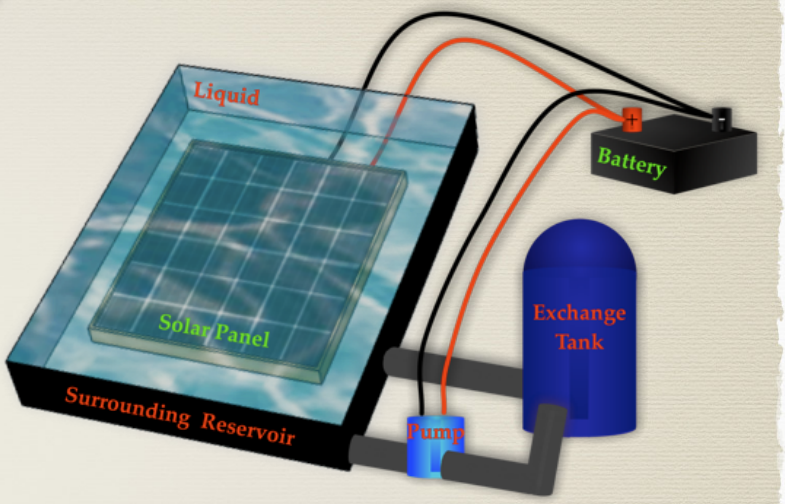

What was Learned

- The symbiotic organism lichen comprised of a fungus and algae exhibit environmental adaptability through close integration, thus living as a single organism

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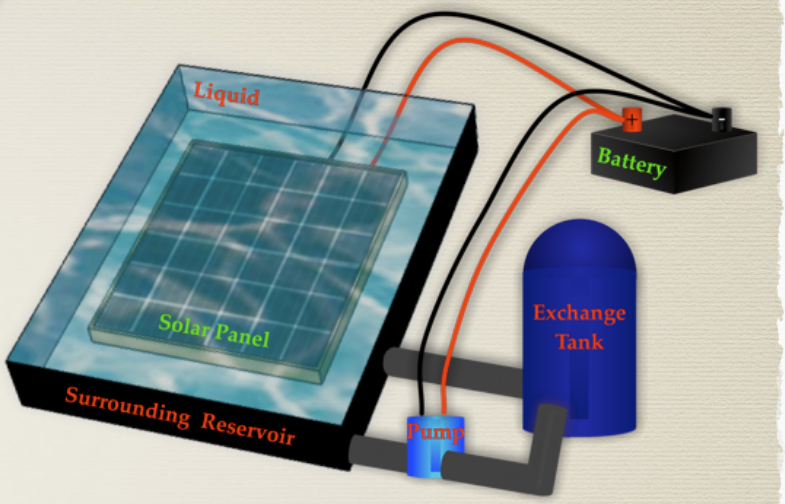

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- The symbiotic organism lichen comprised of a fungus and algae exhibit environmental adaptability through close integration, thus living as a single organism

How to adapt to changing environmental conditions